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Commercial Aircraft Pricing: Application of Lessons Learned

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Executive Summary

Background

The procurement of commercial items presents both opportunities and challenges for the Department of Defense (DoD). Among the challenges is the negotiation of “fair and reasonable” prices with suppliers where competitive sources are not relevant. The Institute for Defense Analyses (IDA) has performed a series of studies developing estimating relationships for the prices of commercial aircraft, variants of which figure in DoD acquisition programs.[1] Commercial aircraft that are used for the basis of military systems are examples of commercial items sold in markets dominated by sellers with market power where competitive sourcing may not be applicable. Lessons learned from this past research can help inform current Air Force negotiations on the prices of current and future systems; of particular interest are the KC-46A and Presidential Aircraft Replacement (PAR) programs. The lessons learned also have implications for the broader portfolio of DoD’s commercial items purchases, particularly those bought in thin markets, and/or markets without competitive sources where negotiation without the benefit of cost data is the norm.

Commercial Aircraft Markets

Price determination by negotiation for commercial items will generally only occur if the supporting markets are not purely competitive. The market for commercial aircraft with a range greater than 3,000 nautical miles is currently a duopoly, with Boeing and Airbus the only producers; in this market, prices are above those that would be paid if the market were purely competitive.

The economics literature provides important insights regarding potential drivers of aircraft price movements over time. These studies show that, although learning will not affect purchase price to the degree evident in a cost-plus contracting environment, there still should be some effect. That is also true for other cost drivers, where the relevant equilibrium relations relate cost directly to price. Given the market power of the sellers, price discrimination through quantity discounts is also a relevant factor that is modeled in the literature.

[1] Bruce R. Harmon, Colin D. Sullivan, and Gregory A. Davis, “Pricing of Commercial Airliners and Engines,” IDA Paper P-4683 (Alexandria, VA: Institute for Defense Analyses, November 2010); unpublished briefings documented updates through 2016.

Price Estimating Relationships

The game-theory models presented in the economics literature are insightful, but too complex to apply to the estimation of fair and reasonable prices. We make use of consultant-reported transaction prices to quantify price drivers, both on the demand and supply side of the market, through least-squares regression analyses. These models explain most of the variance in prices across aircraft models and time; utility associated with commercial airline services, moving people and goods speedily across long distances, can be proxied effectively by a small number of variables, while most supply/cost effects can be captured in a few dimensions. An important insight from the models and supporting data is the long-run decrease in the real prices of commercial aircraft. This trend is confirmed by Boeing's financial data, in which revenue over time indicates higher discounts on reported list prices (which are inflated by more general input price indexes).

Application to the KC-46 and PAR Programs

The price estimating relationships are useful in establishing baseline values for commercial aircraft used by the military. In the application of the models to the KC-46A and PAR programs, we needed additional tools and data to address specifics of those programs/aircraft. The different challenges associated with estimating prices for the KC-46A and the PAR mean different approaches to applying available data, economic theory, and pricing models.

In the KC-46A program, government-funded development includes the creation of a new minor model of the 767, the 767-2C, which was not previously available to commercial customers. In addition, tanker mission system provisions are also incorporated. These factors add challenges to the negotiation of fair and reasonable prices, as pricing history for direct commercial analogs do not exist. The effects of these challenges are mitigated by an acquisition strategy in which the initial competition between suppliers resulted in an award to Boeing in February 2011 of a Fixed Price Incentive Firm contract for the Engineering and Manufacturing Development along with Firm Fixed Price contract options for Low Rate Initial Production Lots 1 and 2, and Not-to-Exceed (NTE) contract options with Economic Price Adjustment for Full Rate Production Lots 3 through 13.[2] It is at Lot 3 (Fiscal Year 2017) where negotiation becomes relevant.

The long time horizen for the KC-46A program means that it is important to take into account both the effect of general industry pricing trends and changes in the specifics of 767 production economics. Our analyses of both of these effects indicates that the

[2] US Department of Defense, "Selected Acquisition Report (SAR), KC-46A Tanker Modernization (KC-46A) as of FY 2017," March 22, 2016.

government may be able to pay lower prices than the NTE prices set in the original competition.

For the PAR, the Air Force will take delivery of two 747-8I commercial aircraft prior to the integration of mission-specific systems.[3] There is no amended type certificate associated with the version of the 747-8 to be used for the PAR program. Thus, the aircraft to be purchased is comparable (with adjustments for the lack of airline interiors) to units purchased by commercial customers.

For the PAR case, current market data for the 747-8I are more relevant. However, even those data must be adjusted for the unique circumstances of the PAR program. These include the relatively low order quantity and the exclusion of airline interiors. These factors are addressed using an economic model quantifying price discrimination/quantity discounts in the aircraft industry, and micro data on the cost of aircraft interiors.

Implications for Other Commercial Items

There are several approaches taken in the analysis of the commercial aircraft pricing for military applications that would be relevant in negotiating prices for other commercial items.

- Understand the market in which the seller operates. This would go beyond "market research" and should address market dynamics as described by economic theory and empirical studies.
- Model market prices as they relate to both supply (cost) and demand (utility) side drivers. This will be challenging—most commercial items bought by DoD and subject to price negotiation are not as homogenous as commercial aircraft.
- Make use of the seller's publicly available financial data to put available pricing data into perspective and to better understand the seller's business model.
- Given the existence of "like type" modifications to items available on the commercial market, it may be advantageous to estimate the discrete costs of these modifications. These costs can be translated into prices based on the economic model driving the relevant industry.

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3 Boeing was awarded a sole source contract on a non-competitive basis for risk reduction activities in January 2016; a purchase agreement at an undisclosed price for two 747-8 aircraft was concluded after the completion of this research.

Contents

1. Background

The procurement of commercial items presents both opportunities and challenges for the Department of Defense (DoD). Among the challenges is the negotiation of "fair and reasonable" prices with suppliers where competitive sources do not exist. The Institute for Defense Analyses (IDA) has performed a series of studies developing estimating relationships for the prices of commercial aircraft, variants of which figure in DoD acquisition programs.[1] Unlike in the case of purpose-built military aircraft, DoD negotiators generally do not have access to the underlying costs or cost estimating relationships derived from historical costs for analogous items. Buying commercial aircraft is substantially different from buying military aircraft or commodity items from other types of commercial suppliers. Lessons learned from this past research can help inform current Air Force negotiations on the prices of current and future systems; of particular interest are the KC-46A and Presidential Aircraft Replacement (PAR) programs. The lessons learned also have implications for the broader portfolio of DoD's commercial items purchases, particularly those bought in thin markets, and/or markets dominated by sellers with market power where competitive sourcing is not relevant.

A. Regulatory Environment

The difficulties in determining a fair and reasonable price are inseparable from what can be considered a commercial item under current laws and regulations. The framework for DoD price and term negotiations of commercial items is set forth in federal law and expressed in terms of implementation in the Federal Acquisition Regulation (FAR), Defense Federal Acquisition Regulation Supplement (DFARS), and various guidance documents provided by the Office of the Secretary of Defense (OSD) and other entities. The subject of commercial item determination and analysis of fair and reasonable prices has attracted a wide array of attention—from industry, DoD budget analysts and policy makers, and US legislators.

[1] Bruce R. Harmon, Colin D. Sullivan, and Gregory A. Davis, "Pricing of Commercial Airliners and Engines," IDA Paper P-4683 (Alexandria, VA: Institute for Defense Analyses, November 2010); unpublished briefings documenting updates through 2016.

New laws are currently being put into regulation that will further define price reasonableness.[2] These new regulations address presumption that an item is commercial if an earlier determination has been made that an item is a commercial item (Section 851), conversion of procurements away from commercial has significant hurdles (Section 856), or, most important, there exist price data to substantiate price reasonableness for procurement of major weapon systems as commercial items (Section 852).[3] DoD is also directed to establish a centralized capability for making commercial item determinations and procurements and to provide guidance for the Department (Sections 851 and 855).

However, the Congress did make it explicit that there is no change to the definition of *commercial item*. The directions from the Congress mainly focus on the threshold of price data required to make a determination for reasonable pricing, and the process for determining adequacy of such information.

1. Truth in Negotiations Act (TINA) (10 U.S.C. 2306a): Certified Cost and Price Data and Commercial Item Exception

It is the acquisition policy of the US government to promote the utmost use of commercial items to meet the government's needs, and to do so in a streamlined manner that follows commercial market best practices.[4] The preference for leveraging commercial items is incorporated into the FAR.[5]

This preference for commercial items—where it brings best overall value to the US government—is reflected in the Truth in Negotiations Act (TINA), as amended.[6] TINA explicitly excludes commercial items from detailed cost and pricing data reporting requirements.

In general, TINA requires offerors, contractors, and subcontractors to make available cost and pricing data.[7] There are minimum dollar thresholds for prime

2 Proposed rule change to DFARS published in Federal Register (81 FR 53101) to implement Sections 851–853 and 855–857 of Fiscal Year (FY) 2016 National Defense Authorization Act (NDAA) and Section 831 of FY 2013 NDAA.

3 The FY 2016 NDAA, Section 855(a)(1), also includes significant presumption that all information technology products or services are commercial items unless determined in writing that no commercial items are suitable. The focus of this paper is non-IT; thus, this subject will not be directly addressed.

4 Federal Acquisition Streamlining Act of 1994 (FASA), Public Law 103-355, Oct 13, 1994.

5 FAR 1.102(b) emphasizes a number of policy goals that bring best value to the US government and satisfy public goals.

6 10 U.S.C. 2306a. Implemented in FAR subpart 15.4.

7 10 U.S.C. 2306a(a)(1).

contractors and subcontractors that require submission of cost or pricing data.[8] This provision for data applies to subcontractors at any tier.[9]

If certain thresholds are satisfied, TINA requires that all such data be certified.[10] Certification of data requires the contractor to certify the accuracy, completeness, and currency of cost or pricing data. From the available information, it appears that the US sales volume of the tanker and PAR have triggered the TINA reporting requirements for certified cost and price data.[11]

a. Exceptions to TINA

As indicated above, there are exceptions to the TINA requirements as follows:

"(b) Exceptions.—

(1) In general.— Submission of certified cost or pricing data shall not be required under subsection (a) in the case of a contract, a subcontract, or modification of a contract or subcontract—

(A) for which the price agreed upon is based on—

(i) adequate price competition; or

(ii) prices set by law or regulation;

(B) for the acquisition of a **commercial item**; or

(C) in an exceptional case when the head of the procuring activity, without delegation, determines that the requirements of this section may be waived and justifies in writing the reasons for such determination; or…"[12]

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8 $700,000 as of 2014. Current published FAR threshold is $700,000 (inflation adjusted from original $500,000 in 41 U.S.C. 103).

9 10 U.S.C. 2306a(a)(C): subcontractors, at any tier, may be required to submit data before the award of the subcontract if the prime contractor and each higher-tier subcontractor have been required to make available cost or pricing data. Implemented in FAR 15.404-3.

10 10 U.S.C. 2306a(2). FAR 15.406-2 addresses certification required by 15.403-4 and 15.403-5. The contents of certified data will be in compliance with a format described in Table 15-2 of FAR 15.408 and the contents will be confirmed as accurate and complete. TINA also establishes requirements for data that are not certified.

11 The head of the procuring agency may still require certified data if below dollar threshold. 10 U.S.C. 2306a(c); FAR 15.403-4(a)(B)(2) (if determined that it is not a commercial item), and 15.404-3(c)(2).

12 10 U.S.C. 2306a(b).

2. Commercial Item

The definition of a commercial item per FAR 2.101 (emphasis added) is as follows:[13]

> "'Commercial item' means—
>
> (1) Any item, other than real property, that is **of a type** customarily used by the **general public or by non-governmental entities** for purposes other than governmental purposes, and—
>
> (i) Has been sold, leased, or licensed to the **general public**; or
>
> (ii) Has been **offered for sale**, lease, or license to the **general public**;
>
> (2) Any item that evolved from an item described in paragraph (1) of this definition through advances in technology or performance and that is not yet available in the commercial marketplace, but will be available in the commercial marketplace in time to satisfy the delivery requirements under a Government solicitation;
>
> (3) Any item that would satisfy a criterion expressed in paragraphs (1) or (2) of this definition, but for—
>
> (i) Modifications of a type customarily available in the commercial marketplace; or
>
> (ii) Minor modifications of a type not customarily available in the commercial marketplace made to meet Federal Government requirements. Minor modifications means modifications that do not significantly alter the nongovernmental function or essential physical characteristics of an item or component, or change the purpose of a process. Factors to be considered in determining whether a modification is minor include the value and size of the modification and the comparative value and size of the final product. Dollar values and percentages may be used as guideposts, but are not conclusive evidence that a modification is minor; or
>
> (4) Any combination of items meeting the requirements of paragraphs (1), (2), or (3) of this definition that are of a type customarily combined and sold in combination to the general public;"

[13] FAR 2.101, Definitions. For purposes of commercial items, "general public" does not include the federal government or a state, local, or foreign government (FAR 202.101; PL 110-181, section 815(b)).

The above FAR language allows a very broad interpretation of a commercial item. DoD has purchased commercial items as diverse as transport aircraft, computers, medicines and fuel.[14]

a. *Precision Lift, Inc. v. US*: Court Case involving Definition of Commercial Item

In a bid protest ruling involving a solicitation from the Army National Guard Bureau, the United States Court of Federal Claims upheld an administrative court determination[15] that a maintenance platform for helicopters was a commercial item, although the manufacturer has never previously produced any of the platforms that were the subject of the procurement dispute.[16] The Court provided an analysis that is pertinent to the situation at hand by reviewing the FAR definition of a commercial item.

First, the item was found to be "of a type" customarily used by the general public (or non-governmental entities for purposes other than governmental purposes) since the administrative record indicated that the platforms are a standard, non-patented and non-proprietary maintenance platform that have been in service for years. Moreover, the Court found they are in common usage. That is, the product is essentially a commodity.

The next step, per the Court's analysis, is to determine if the item has been sold or offered to the general public. The court case at hand stated that although the item had not been sold, it had been offered for sale since the administrative record indicated the item was touted in advertising and marketing efforts available to the public, and the proposal to the US government included a standard product brochure.

In making its decision on the definition of a commercial item, the court stated:

> However, this is not to say that the statute [the FAR] is clear. The definition is broad, unclear, and will be interpreted as setting the "commercial item" standard very low. If the Federal Acquisition Regulations are intended to use the term in a very limiting way, its [the FAR's] plain language does not communicate that intent.[17]

Since this case has apparently not been overruled or appealed, it stands as the most authoritative statement on interpreting FAR 2.101.

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[14] See Commercial Item Description (CID) Guidance on "Key Policy Documents," DoD Defense Standardization Program, http://www.dsp.dla.mil/Policy-Guidance/Key-Policy-Documents/.

[15] The post-award protest was filed with the Government Accountability Office (GAO).

[16] *Precision Lift, Inc. v. U.S*., 83 Fed. Cl. 661. Involves a bid protest by a firm that did not win a US government contract (Precision Lift) for helicopter maintenance platforms; the Court agreed with the GAO determination that Spika Welding & Manufacturing, Inc. was correctly awarded the contract.

[17] Ibid.

b. Of a Type

The court did not discuss the key phrase “of a type” in rendering its decision on the definition of a commercial item. However, this matter is covered in both the FAR definition and the *Commercial Item Handbook (Version 2.0)* that was prepared by the Office of the Secretary of Defense for Acquisition, Technology & Logistics (Acquisition Initiatives).[18] In sub-section (3) (i and ii) (FAR definition of a commercial item), discussed on page 4, items that require modifications of a type customarily available in the commercial marketplace, or require minor government-unique modifications, can still be considered commercial items.

The *Commercial Item Handbook* expounds upon the definition of “of a type.”[19] First it notes that the definition of a commercial item is broad. Next, it states that commercial items do not have to be commercial off-the-shelf:

> Items that require modifications of a type customarily available in the commercial marketplace, or require minor Government-unique modifications, can still be considered commercial items. To qualify as representing a minor modification, of a type not customarily available in the commercial marketplace made to meet Federal Government requirements, the modification must significantly alter the nongovernmental function or essential physical characteristics of an item or component, or change the purpose of a process.[20]

It is acknowledged that the use of the phrase “of a type” is broad and offers much latitude in what is considered to be used by the general public. Nonetheless, the Handbook in regard to “of a type” states:

> As a caveat, it is noted that the item must always fall within the definition of a commercial item under the FAR; this leeway is not license to procure military unique items which are not within the scope of that definition.[21]

B. Overview of Programs

The programs of most interest are the KC-46A tanker and the PAR. The nature of the commercial content differs between the two systems.

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[18] Office of the Secretary of Defense, Acquisition, Technology and Logistics (Acquisition Initiatives), *Commercial Item Handbook (Version 2.0)*, undated.

[19] Ibid., 2. The Handbook states that the commercial definition is not limited to items acquired from prime contractors but also extends to items acquired from subcontractors at all tiers, including items transferred from a contractor’s divisions, affiliates, or subsidiaries. The burden of complying with the FAR definition of a commercial item would presumably pertain to all tiers of contractors.

[20] Ibid., 1.

[21] Ibid., 2.

1. KC-46A

In the KC-46A program, government-funded development includes the creation of a new minor model of the 767, the 767-2C, which was not previously available to commercial customers. The 767-2C includes a combination of features available in other Boeing commercial aircraft including freighter floors and doors, convertible passenger capability, an upgraded cockpit, and higher maximum take-off weight (MTOW). In addition, tanker mission system provisions are also incorporated; although these features were not available on previous Boeing commercial aircraft, they are "of a type" changes that commercial customers might specify—e.g., added provisions for non-standard buyer-furnished equipment (BFE). Boeing has applied for a Federal Aviation Administration "amended type certificate" (ATC) for the 767-2C. Given the ATC, the 767-2C will be commercially available to other customers. All of these factors add challenges to the negotiation of fair and reasonable prices, as pricing history for direct commercial analogs do not exist. The effects of these challenges are mitigated by an acquisition strategy in which the initial competition between suppliers (resulting in the choice of Boeing over Airbus in February 2011) provided for price discovery. The award covered a Fixed-Price Incentive Firm contract for the Engineering and Manufacturing Development along with Firm Fixed Price contract options for Low Rate Initial Production Lots 1 and 2, and Not-to-Exceed (NTE) contract options with Economic Price Adjustment (EPA) clause for Full Rate Production Lots 3 through 13.[22] It is at Lot 3 (FY 2017) where negotiation becomes relevant.

2. Presidential Aircraft Replacement (PAR)

For the PAR, the Air Force will take delivery of two 747-8I commercial aircraft prior to the integration of mission-specific systems, including electrical power upgrade, a mission communication system, executive interiors, military avionics, a self-defense system, and autonomous loading systems. There is no ATC associated with the version of the 747-8 to be used for the PAR program. Thus, the aircraft to be purchased is comparable (with adjustments for the lack of airline interiors) to units purchased by commercial customers of the passenger or Very Important Person (VIP) aircraft and thus fits the criteria for a commercial item. Boeing was awarded a sole source contract on a non-competitive basis for risk reduction activities in January 2016; two 747-8 aircraft are to be purchased in FY 2017.[23]

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[22] US Department of Defense, "Selected Acquisition Report (SAR), KC-46A Tanker Modernization (KC-46A) as of FY 2017", March 22, 2016.

[23] US Department of Defense, "Fiscal Year (FY) 2017 President's Budget Submission, Air Force Justification Book Volume 2 of 3, Research, Development, Test & Evaluation, Air Force Vol II," February 2016.

2. The Economics of the Commercial Aircraft Market

The market for commercial aircraft with a range greater than 3,000 nautical miles (NM) is currently a duopoly, with Boeing and Airbus the only producers. In a duopoly such as this, the participants have a degree of market power not evident in more competitive markets. The suppliers' choice of quantity (price) has an effect on market price (quantity demanded) as each supplier contributes a large part to industry output. Also, given learning in the aircraft industry, the choice of quantity for a given time period affects costs in future time periods. This combination of attributes means that for any given product line and time period, price can be below marginal cost (startup period)[24] or above marginal cost (mature program). Also, given market power (the supplier faces a downward sloping demand curve), price discrimination is also evident. This contrasts with a competitive market in which all firms are price takers; the cost of production for any given firm does not affect the market price. All of these factors contribute to the difficulty in arriving at fair and reasonable prices for commercial aircraft.

A. Overview of the Literature

These observations are drawn from a substantial academic literature on the economics of the commercial aircraft industry, in which price determination is an important aspect of much of the research.[25] This literature provides important insights regarding potential drivers of aircraft price levels and movements over time. These studies[26] show that, although learning will not affect purchase price to the degree evident in a contracting environment—as in the military aircraft procurement, where prices are negotiated based on cost—there still can be some effect. This should be true for anything

[24] Due to learning-by-doing, the first quantity produced has a very high cost. Prices in the startup period are usually observed to be below marginal costs.

[25] The discussion of the economics literature draws from Harmon, Sullivan, and Davis, "Pricing of Commercial Airliners and Engines."

[26] Richard Baldwin and Paul Krugman, "Industrial Policy and International Competition in Wide-Bodied Jet Aircraft," in *Trade Policy Issues and Empirical Analysis*, ed. Robert E. Baldwin. (Chicago: University of Chicago Press for the National Bureau of Economic Research, 1988); C. Lanier Benkard, "A Dynamic Analysis of the Market for Wide-Bodied Commercial Aircraft," *Review of Economic Studies* 71, No. 3 (July 2004): 581–611, https://web.stanford.edu/~lanierb/research/Dynamic_Aircraft_RES.pdf; and Douglas A. Irwin and Nina Pavcnik, "Airbus versus Boeing Revisited: International Competition in the Aircraft Market," *Journal of International Economics* 64, No. 2 (December 2004): 223–45, doi:10.1016/j.jinteco.2003.08.006.

that affects the cost structure of the industry or a given product line. For example, estimated price increases that followed the 1992 reduction in government subsidies were coincident with calculated increases in producer costs.[27] Other possible cost drivers that could show up in price include labor productivity secular trends and cyclical movements. Some fixed costs will be "quasi-fixed"—portions of labor inputs that are sticky relative to production rate. This was noted in a Bureau of Labor Statistics (BLS) study of labor productivity in the aircraft industry.[28] The BLS found that labor productivity was highly procyclical—higher output measures were associated with higher productivity growth as quasi-fixed portions of labor were spread over more units. Their data also show a longer term upward trend in labor productivity of 1.5 percent to 2.5 percent per year.

B. Modeling Approaches

The models of the aircraft industry presented in the economics literature have by necessity been abstracted from a complex reality. They have at least four things in common:

- Use of a multi-period dynamic framework,
- Rules guiding the strategic behavior of suppliers in a duopoly/oligopoly situation where game-theoretic approaches are used to solve for industry equilibrium,
- Inclusion of learning curves in the supply functions of the firms, while taking into account the dynamic effects of learning on firm decisions, and
- Demand relations reflecting the derived demand of aircraft as an input to the production of air services.

All the models take the manufacturers as value maximizers over an extended time horizon where the value function is: assuming a homogeneous product, for firm *j*,

$$V_j = \sum_{t=0}^{T} R^t (p_{jt} q_{jt} - c_{jt} q_{jt}), \tag{1}$$

where Vj is the net present value for firm j, R is a discount factor and p_{jt}, q_{jt}, and c_{jt} are the relevant price, quantity, and marginal cost.[29] Modifications to this basic setup were made

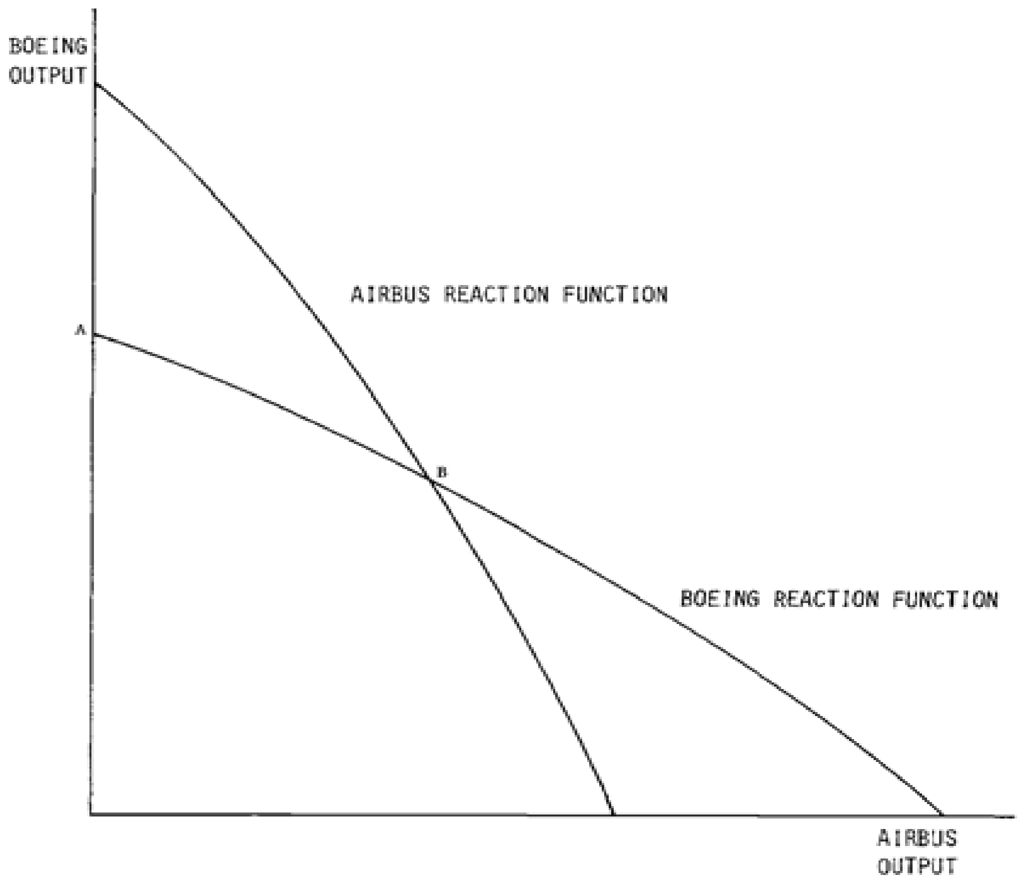
[27] Irwin and Pavcnik, "Airbus versus Boeing Revisited."

[28] Alexander Kronemer and J. Edwin Henneberger, "Productivity in Aircraft Manufacturing," *Monthly Labor Review* (June 1993): 24–33, https://www.bls.gov/mfp/mprkh93.pdf.

[29] The definition of marginal cost in most of this literature is not the cost of the last aircraft built during the time increment, but the average cost over that time period, implying the inclusion of recurring fixed costs.

by the different researchers to reflect additional assumptions. The firms' strategic behavior is portrayed either as quantity setting (Cournot game) or price setting (Bertrand game). The choice of q_{jt} will affect both the current price through the demand relation, $p_{jt}=f(Q_{jt})$, where $Q_{jt}=\sum_{j=1}^{J} q_{jt}$, and current and future costs, through the learning curve. In the Bertrand game, choosing p_{jt} will affect q_{jt}, which in turn will affect future costs through the learning curve. The models vary in complexity and realism.

Baldwin and Krugman (1988) present the simplest model; it is calibrated on data from the competition between the Airbus A300 and Boeing 767, where the counterfactual, a 767 monopoly in the low-end wide-body (WB) aircraft market, is compared to the market as modeled as a duopoly where the A300 and B767 are treated as perfect substitutes.[30] Equilibrium solutions were calculated for a Cournot game. Figure 1 shows a simple, single-period solution.



Source: Baldwin and Krugman, "Industrial Policy and International Competition in Wide-Bodied Jet Aircraft."

Figure 1. Example Solution to Cournot Game for Boeing/Airbus Duopoly

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[30] Baldwin and Krugman, "Industrial Policy and International Competition in Wide-Bodied Jet Aircraft."

Point B is the equilibium duopoly quantity, while Point A is the Boeing equilibrium monopoly quantity with no Airbus entry (i.e., the counterfactual with no Airbus government subsidy), where total market quantity is lower and price and economic rents to Boeing are higher. In comparison to a purely competitive market, the duopoly solution results in a lower quantity, higher price, and greater economic rents to the sellers.

A single-period equilibrium solution for market price (p_t) was determined as

$$p_t = \frac{c_t + z_t}{1 - (1\text{-}s)/E}. \tag{2}$$

where c_t is the marginal cost of the aircraft, z_t is the shadow value of current production arising from reductions in future costs due to learning, s is the market share of the subject firm, and E is the demand elasticity ($E > 0$).[31] The z_t term is negative and accounts for observed prices that are lower than costs in the early part of the program; z_t will go to zero at the end of a program's life. This relation does show that price is related to cost, but will tend to be more stable over time. Note that the simplified model does not separately model fixed costs. Here the marginal costs are interpreted as the average cost of a given period's production—the assumption is that the producer decides what quantity to produce, or whether to produce at all, in the prior period. Their simulations did indicate that some learning should be evident in the equilibrium prices. For a long-lived program like the B767, z_t will become less and less relevant, and price will more closely follow cost. In such a situation, the strategic behavior of the producer may follow a Bertrand game, where some price that ensures an adequate mark-up over cost is set, and quantities sold become a fall-out.

The more complex models in Benkard (2004) and Irwin and Pavcnik (2004) estimated demand relations for portfolios of Boeing and Airbus WB aircraft using statistical methods. Transaction prices used in the statistical analyses were obtained from airline consultants AvMark (Benkard) and Airline Monitor (Irwin and Pavcnik). Utility to airlines was proxied by the number of seats, the number of engines,[32] and a freighter dummy variable (Benkard); and range, seats, and MTOW (Irwin and Pavcnik). The statistical analyses also included petroleum price and Gross Domestic Product (GDP) as independent variables. As with Baldwin and Krugman, the supply (cost) relation took into account learning; Benkard also included fixed costs. Simulating equilibrium values for quantity, price, and cost was done using Cournot game assumptions in Benkard (20-year simulation), and Cournot and Bertrand game assumptions in Irwin and Pavcnik.

[31] Denote demand with x. The price elasticity of demand is $-(\Delta x/\Delta p)\ (p/x)$, which measures the percentage change in demand in response to a 1 percent change in price.

[32] The number of engines is an indicator of efficiency—given the same number of seats, an aircraft with more engines will be less efficient at producing revenue for the airline.

Figure 2 presents simulation results for prices and costs as expressed as the markup of price on cost.

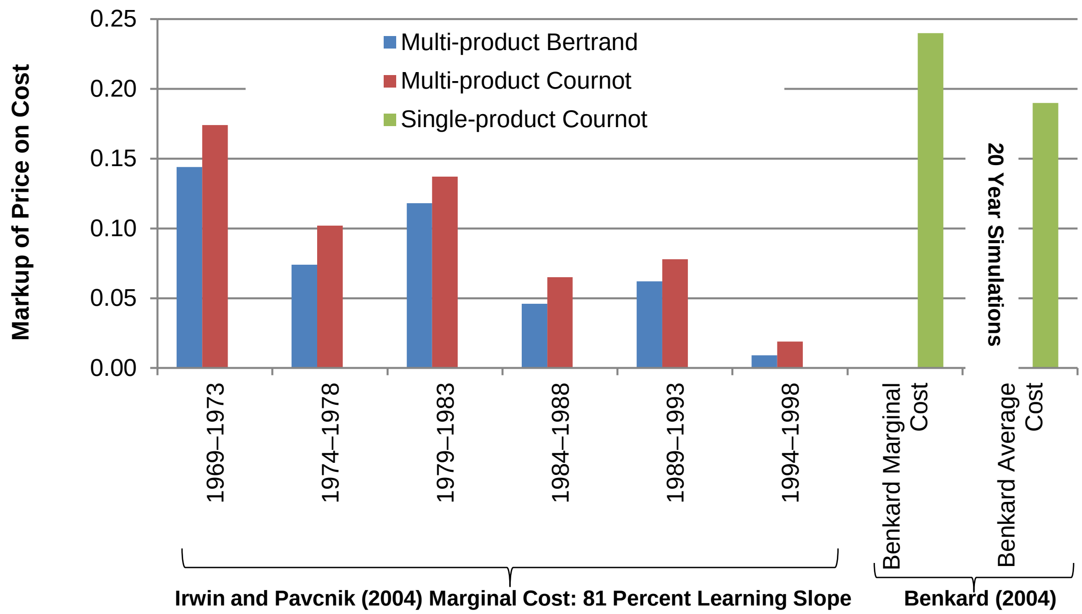


Figure 2. Comparison of Markup Rates for Aircraft Market Simulations

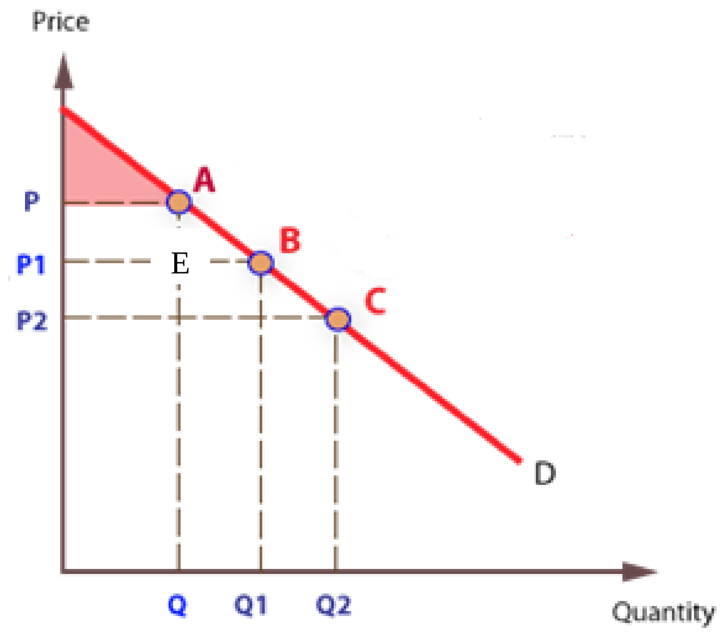
For Irwin and Pavcnik, the learning curve slope and first unit costs are calibration parameters, while for Benkard, they are based on actual cost experience for the Lockheed L1011, which is then scaled by aircraft weight for the other WB market entrants. Their results also show some learning effects reflected in prices over time.

C. Quantity Discounts and Price Discrimination

One effect of the market power of producers is their ability to price discriminate between different buyers. The economics literature surveyed above treats the buyers of commercial aircraft as homogenous (other than in random error terms) and quantity discounts were not explicitly modeled. Quantity discounts can be the result of at least two different phenomena. The first is simply the effect of lower costs for higher quantities—either due to the effect of learning (both for the current period and on future costs) or the spread of fixed costs across more units (this is consistent with the assumption that firm behavior treats recurring fixed cost in the production period as marginal costs). This is reflected to some degree in the cost functions included in the models and the strategic behavior of producers.[33] Quantity discounts are also a strategy for price discrimination—

[33] The manufacturers should favor large orders not only because of the cost effects in the execution years, but also because they contribute to later cost performance though learning—this is the economic explanation for large launch discounts.

by separating consumers into groups, producers can limit the amount of their consumer surplus, while sustaining sales volume. For example, airline A is willing to pay a $120 million unit price, but airline B will only pay $110 million. If a single price is set at $110 million to capture both sales, the producer will lose $10 million/aircraft in surplus to airline A. The producer would like to devise a pricing scheme where they sell at $120 million to airline A and $110 million to airline B. This is shown in a graphical example in Figure 3.



Source: Economicsonline.co.uk.

Figure 3. Price Discrimination Example

Under this scheme, the consumer surplus to airline A decreases to the red triangle. Airline B's consumer surplus is the triangle ABE. The producer can increase its producer surplus by $pAEp_1$.

One such price discrimination strategy would be to employ quantity discounts as a marketing tool. Quantity discounts are difficult to capture empirically using representative transaction prices as reported by the airline consultants. Onishi (2016)[34] makes use of data on individual aircraft transactions for the years 1978–1991, available from the Department of Transportation (DOT). He uses these data and additional information to estimate quantity discounts. There are two quantity measures that take into account both the size of a given order and each airline's total quantity bought relative to

[34] Ken Onishi, "Quantity Discounts and Capital Misallocation in Vertical Relationships: The Case of Aircraft and Airline Industries" (February 29, 2016), doi: 10.2139/ssrn.2739658.

the total quantity bought for a given aircraft model. Price differences that could be driven by quantity are expressed as discount ratios from the mean price for a given aircraft model. Price discount ratios are calculated per order:

$$D_{jit} = \frac{\overline{p_J} - p_{jit}}{\overline{p_J}}, \tag{3}$$

where D_{jit} is the discount ratio for order *t*, associated with customer airline *i* and aircraft model j, $\overline{p_J}$ is the mean price for all sales of aircraft model *j*, and p_{jit} is the real price of order *t* (all prices are inflation-adjusted). Note that $\overline{p_J} = \frac{\sum_{i,t} p_{jit}}{I \times T}$ where I and T are the numbers of airlines and orders for model *j*. If $D_{jit} > 0$, airline *i* gets price discounts. If $D_{jit} < 0$, airline *i* pays a premium over the mean price when it buys model *j*.

The two quantity measures are specified as indexes below. The first accounts for the relative size of a given order, where

$$q^N_{jit} = \frac{Order\ Quantiy_{jit}}{Total\ Accumulated\ Quantiy_j}, \tag{4}$$

and the second accounts for the relative airline quantity over all orders for a given model:

$$q^A_{jit} = \frac{Airline\ Accumulated\ Quantiy_{jit}}{Total\ Accumulated\ Quantiy_j} \tag{5}$$

In terms of the two drivers of quantity discounts, q^N_{jit} and q^A_{jit}, the first can be thought of as more closely related to the cost effect and the second with price discrimination.

Given the metrics for price discounts, quantity measures, and the data available, a pooled ordinary least squares (OLS) regression was estimated:

$$D_{jit} = \alpha_i + \alpha_j + \beta^N q^N_{jit} + \beta^A q^A_{jit} + \sum_{k=1}^{K} \beta_k x_{kjit} \tag{6}$$

Where α_i and α_j are intercepts for each airline and aircraft model, β^N and β^A are coefficients on the quantity variables, while the β_ks are coefficients on a vector of control variables (the x_{kjit}s). The control variables include a time trend, a measure of prior cumulative quantity by aircraft model, and whether the aircraft model had a direct competitor. These terms control for changes in market structure and dynamics over the sample period, thus isolating the effects of quantity discounts from other drivers of differences from the mean prices.

The results indicate that the airline effect dominates the order size effect with β^A= .60 and β^N= .10, while the parameters are statistically significant at the .01 and .10 levels, respectively. Values for the remaining coefficients in the regression should drive estimated D_{jit} toward zero at the mean values of the independent variables. Given this,

we can apply the regression coefficients to estimate relative quantity discounts for the contemporary aircraft of interest.

In the next chapters we will incorporate the idea of price discounts into our analysis explicitly.

3. Modeling Commercial Aircraft Prices

A. Methodology

We use least-squares regression techniques to define and test specifications of the price estimating relationships. Prices are treated as dependent variables and related to independent variables, which we hypothesize to be price drivers. In the case of least-squares regressions, the functions are defined by parameter estimates on the independent variables determined by minimizing the squared errors of the regression line from the actual data. The price estimating relationships take on the multiplicative form:

$$p_j = f(x_j, \beta)e^{u_j}, \tag{7}$$

where p_j is the value of the observed price for aircraft j, $\mathbf{x_j}$ is the vector of independent variables, β is the vector of parameter estimates, and u_j is the error term. Without loss of generality, assume that the equation takes on the intrinsically linear form with an intercept, one regressor x_1 (price driver), and one dummy variable D,

$$p_j = \beta_o x_{1j}^{\beta_1} \beta_2^{D_j} e^{u_j}, \tag{8}$$

and then OLS regression techniques can be applicable. To do this, the equation is transformed to a log-log form:

$$\ln(p_j) = \ln(\beta_0) + \beta_1 \ln(x_{1j}) + \ln(\beta_2)D_j + u_j. \tag{9}$$

OLS will produce parameter estimates of $b_0 \equiv ln(\beta_0)$, $b_1 \equiv \beta_1$, and $b_2 \equiv ln(\beta_2)$. Both β_0 and β_2 can be recovered by taking an anti-logarithmic transformation of b_0 and b_2, i.e., by calculating e^{b_0} and e^{b_2}. The parameter estimate b_1 has a natural interpretation of elasticity, measuring the percentage change in price with respect to a 1 percent change in x_1. The parameter b_2 represents a change in price ($\Delta p_j/p_j$) when the dummy variable switches its value from 0 to 1.

When describing the estimating relationships, information presented includes R^2, adjusted R^2, the standard error of the estimate ($\hat{\sigma}$), and the t-statistics (which are the ratios of the parameter estimates to their standard errors), as well as associated levels of statistical significance for each of the parameter estimates. We generally exclude variables whose parameter estimates are not significant at the 0.1 level, although some exceptions are made. In a linear model, R^2 measures the proportion of the total variance

in the data explained by the model. Although this is not strictly true for most of our models because they are nonlinear, the R^2 analog provides useful information about the relative fit of the models. Adjusted R^2 presents this information adjusted for the number of independent variables in the regression. R^2 and adjusted R^2 are calculated from the data and model after they are transformed back from log space to arithmetic space. $\hat{\sigma}$ is calculated in log space; it can be converted into minus/plus percentages of price in the original space by calculating values for $\left(e^{-\hat{\sigma}}\right) - 1$ and $\left(e^{+\hat{\sigma}}\right) - 1$. Measures derived from the standard errors provide information regarding the uncertainty of the estimates.

B. Data

The IDA team used data from airline industry consultants to build price estimating relationships for commercial aircraft. Airlines and manufacturers withhold transaction price information from public release, and DOT transaction price data for contemporary experience are not available. Although list prices are available on Boeing and Airbus websites, aircraft are generally sold at a substantial discount from list. The airline consultants estimate prices for a variety of clients including aircraft purchasers, lessors, insurers, and investors. They are coy about their estimating methods; they seem to extrapolate from a limited number of actual data points (often from their clients) based on financial valuation models.

IDA's previous analysis of the KC-767 purchase price noted uncertainties associated with reported aircraft price data:

> The complexity of the transactions comes from two sources: the variation in content from one sale to another, and the nature of the contractual arrangements involved. Both sources of complexity make it difficult to interpret any known historical sales prices.
>
> The content included in a given sale may on the one hand include spare parts, training, and maintenance support. On the other hand, the sales price may not include buyer furnished equipment such as interiors, in-flight entertainment, seats and galleys. Additionally, 767 aircraft, like most commercial models, are sold with a wide range of features such as upgraded avionics, engines, fuel capacities, maximum gross takeoff weight and cargo handling systems.[35]

This uncertainty was addressed for 767 pricing by collecting data from multiple sources, representing multiple years and transactions. This general strategy was expanded to the broader commercial aircraft market by statistically defining price estimating relationships. The goal was to abstract from the available data some reference value for a

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[35] J. Richard Nelson et al., "Purchase Price Estimate for the KC-767A Tanker Aircraft (Redacted Version)," IDA Paper P-3802 (Alexandria, VA: Institute for Defense Analyses. July 2003). (Unclassified//FOUO)

given aircraft model based on the consultants' pricing data, regardless of the conditions of specific transactions or possible measurement error associated with the individual data points used. The regression analyses employed generated the expected values of prices conditioned on measures of aircraft utility and other price drivers. The statistical analyses in turn provided measures of estimation error that partially reflect uncertainties in the data.

IDA price estimating research was first performed in 2009–2010;[36] data from Airline Monitor, AVITAS, and Morten Beyer & Agnew (MBA) were used. These data included reported prices through 2009. The AVITAS and MBA data showed similar prices for the same aircraft model, while the Airline Monitor data showed consistently higher prices, particularly for WB aircraft. Also, Airline Monitor's time series data showed almost no price variability between years, and price data for discontinued aircraft models were reported after they ceased delivery. As AVITAS did not include time series data by aircraft model, we chose to update only the MBA data; the updated data used in modeling included reported prices through January 2016. MBA presented "Base Value" and "Current Market Price" data—in most cases the two values were the same, but when they were different we used the Current Market Price value. Prices were for typical airline configurations, including interiors/BFE. Table 1 shows the coverage by year for the MBA data used in the regression modeling. Note that there was a gap in data reporting in 2010 and 2011.

[36] Harmon, Sullivan, and Davis, "Pricing of Commercial Airliners and Engines."

Table 1. Data Coverage

Manufacturer	Aircraft	Years in 2010 Study	Additional Years in 2016 Update
Airbus	A330-200	1998–2009	2012–2016
Airbus	A330-300	1996–2009	2012–2016
Airbus	A330-300F	NA	2014–2016
Airbus	A380-800	N/A	2012–2016
Boeing	737-600	1998–2006	N/A
Boeing	737-700	1998–2009	2012–2016
Boeing	737-800	1998–2009	2012–2016
Boeing	737-900	2001–2005	N/A
Boeing	737-900ER	2006–2009	2012–2016
Boeing	747-8	N/A	2012–2016
Boeing	747-F	N/A	2016
Boeing	767-200ER	1988–1991, 2000–2007	N/A
Boeing	767-300ER	1988–2009	2012–2013
Boeing	767-300F	NA	2014–2016
Boeing	767-400ER	2000–2002	N/A
Boeing	777-200	1995–2006	N/A
Boeing	777-200ER	1997–2009	2012–2014
Boeing	777-200LR	2007–2009	2012–2014
Boeing	777-300	1998–2006	NA
Boeing	777-300ER	2005–2009	2012–2016
Boeing	777F	NA	2014–2016
Boeing	787-8	N/A	2012–2014
Boeing	787-9	N/A	2016

All dollar amounts are measured in CY16 dollars. The inflation adjustment is made using the US GDP deflator as reported by the Bureau of Economic Analysis (BEA). The effect of other economic factors (fuel price, world GDP, cumulative aircraft quantity) are weighted based on estimates from panel data analyses that are described later.

Aircraft characteristics used as cost drivers in the regressions were open source data obtained primarily from the aircraft manufacturers' websites. Price drivers for cross-sectional analysis were aircraft characteristics fixed over time reflecting utility to airlines. Different independent variables and subsets of data were included in the resulting price estimating relationships. Either MTOW, Seats and Range (Seat Miles),[37] or Payload was

[37] Seat Miles is a measure of an aircraft's passenger-carrying capacity. It is equal to the number of seats available multiplied by the maximum range in miles.

used as the primary driver. These drivers are presented graphically for the aircraft in the data sample in Figure 4.

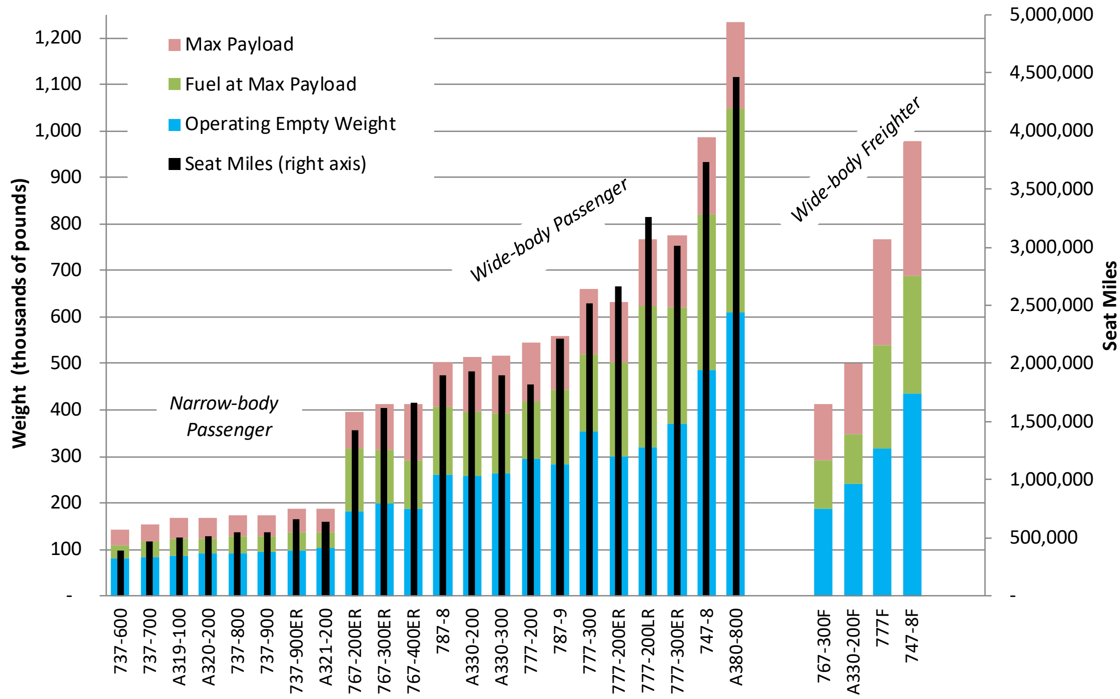

Figure 4. MTOW and Seat Miles for Commercial Aircraft Sample

Data can be further broken down by aircraft model. An aircraft model is introduced, manufactured, and phased out over time. Therefore, a given model is usually observed in multiple years over a specific range of years. Some drivers change over time and model. For example, the variables representing and measuring utility (demand) and cost (supply) affect prices over time. The economics literature informs our choice of independent variables. Table 2 provides summary data for key variables.

Table 2. Summary Statistics for Key Variables

	Fixed Aircraft Characteristics			Variables that Change Over Time				
	Seats	Range (NM)	MTOW (lbs)	Annual Quantity (Aircraft Family)	Cumulative Quantity (Aircraft Family)	World GDP Growth	World GDP Growth (De-trended)	Aviation Fuel Price/Gallon (2016 Dollars)
Mean	261	5,826	534,276	131	2,136	3.6%	0.2%	$1.57
Minimum	107	3,066	143,500	6	13	-0.1%	-1.8%	$0.57
Maximum	525	10,817	1,234,588	495	9,325	5.7%	3.1%	$3.33

C. Cross Section Models

In presenting the cross-section models, our emphasis is on the results most relevant to the WB aircraft. We selected only those aircraft models observed in the 2016 data. Each data line represented model *j*. Eleven models in total were observed in 2016 (N = 11). Each model was associated with time-invariant aircraft characteristics. In developing price estimating relationships, we tried two different modeling approaches: in the first, MTOW was our primary explanatory variable; in the second, the variable measuring seats and range was used.

A baseline empirical outcome was found as follows (standard errors are included under the parameter estimates):

For WB aircraft,

$$\underset{}{ln(p_j) = -11.06 + \underset{(.174)}{1.195}\, ln(MTOW_j) - \underset{(.132)}{0.268}(4Engines_j)}$$

Or, equivalently,

$$p_j = 0.0000157 \cdot MTOW_j^{1.195} \cdot 0.765^{4Engines_j},$$

where $4Engines_j$ is a dummy variable, taking 1 for a four-engine aircraft and 0 for a two-engine aircraft.

The MTOW specification allowed us to include freighter aircraft in the sample. For a given MTOW, a four-engine aircraft has a lower price than a two-engine aircraft due to lower fuel efficiency. This effect was tested using the 1/0 dummy variable. All parameter estimates were significant at p = .08 or better. When seats and range were used as independent variables, the freighter aircraft were no longer included in the data sample. The MTOW model showed a substantially better fit than the Seats and Range model. One reason for this may be the ambiguity regarding seating configurations for the passenger aircraft. We also tried different combinations and transformations of the constituents of MTOW (e.g., empty weight, weights for payload and fuel), but found that MTOW fit the best. Figure 5 presents information for the preferred MTOW relationship for WB aircraft, including MBA-reported and model estimated prices, as well as measures of statistical fit.

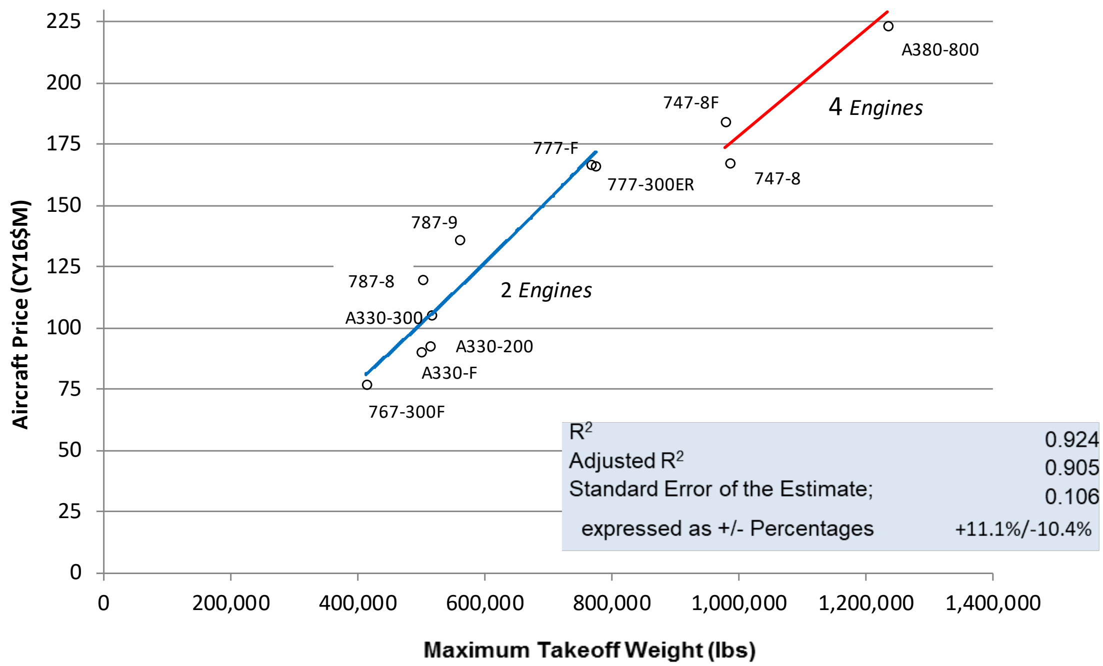

Figure 5. MTOW Model for WB Aircraft

D. Pooled OLS Models

Our data were a mix of cross-section (data by aircraft model) and time series (for a given model). The time series data sample included observations from 1988 to 2016, covering periods that vary by model; the data ranges are shown in Table 1 (page 20). Our empirical regression took the logarithmic form:

$$p_{jt} = \mathbf{z}_j\alpha + \mathbf{x}_{jt}\beta + \varepsilon_{jt}, \tag{10}$$

where the j subscript indexed each model, $\mathbf{z}_j$ was a vector containing a constant term and variables for each model that are fixed over time, and $\boldsymbol{x}_{jt}$ was a vector of regressors that varied over model and time.

In terms of the price estimating model, the aircraft-model-specific variables fixed over time (e.g., Seat Miles and MTOW) were contained in $\mathbf{z}_j$, while the x_{jt}s were the economic variables that changed over time and model (including delivery quantities to capture learning). If the observed aircraft-characteristic variables fully define $\mathbf{z}_j$, then

OLS can be used to estimate the model.[38] Given positive diagnostics regarding $\mathbf{z}_j$, we chose to estimate the price estimating relationships using OLS.[39]

For the aircraft model-specific variables (the z_js) we found either Seats and Range or MTOW to be statistically significant. For the updated data sample, we did not find a Freighter effect. For the economic variables, we experimented with different time lags and forms of world GDP growth,[40] fuel prices,[41] delivery rates, and aircraft cumulative quantity, as well as a time trend. As there were already substantial correlations between time, cumulative aircraft quantity, and fuel price, we used the de-trended series for GDP growth.

The net effect of market cycles on aircraft prices is an interesting empirical question. There is a supply-side argument that higher production rates would mean lower unit costs and prices.[42] The demand-side argument is that higher economic growth would raise the utility of aircraft to the airlines and prices would rise. Although these are two different effects, they were highly correlated with one another in the data. We found that higher GDP growth is associated with higher prices, and that measures of delivery rate were either statistically insignificant when entered with GDP growth, or carried the same sign. In the end we chose de-trended world real GDP growth, lagged two years, to capture the effect of market cycles on prices.

The impact of other x_{jt}s were not ambiguous, as the demand and supply/cost effects were more clearly delineated. Fuel price was a demand-side driver, where higher fuel prices were expected to result in lower aircraft prices. Higher cumulative quantities should result in lower costs and prices. Long-term increases in productivity should lead to lower real prices over time for a given aircraft capability.

For our preferred baseline pooled OLS, we identified five price drivers: maximum takeoff weight ($MTOW_j$), cumulative quantity ($CumQ\_L1_{jt}$), de-trended world real GDP

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38 William H. Greene, *Econometric Analysis*, 5th Edition (Upper Saddle River, NJ: Prentice Hall, 2002).

39 Although there was evidence in the regression results that assumptions required for OLS to be the best unbiased linear estimator were violated (unequal error variances across panels/heteroskedasticity and correlation of errors across time within each panel/serial correlation), we judged alternatives to address these problems (generalized least squares or the use of cluster robust standard errors) inappropriate, given our data sample.

40 Data from the International Monetary Fund, “World Economic Outlook, Subdued Demand: Symptoms and Remedies,” October 2016, http://www.imf.org/en/Publications/WEO/Issues/2016/12/31/Subdued-Demand-Symptoms-and-Remedies.

41 Data from the US Energy Information Agency, “US Kerosene-Type Jet Fuel Retail Sales by Refiners” (source key A503600002). Converted to CY16 prices using the GDP deflator.

42 There were also offsetting supply-side arguments; production spikes may be associated with increased prices for inputs and increasing marginal costs.

growth rate ($WGDP\_L2_{jt}$), fuel price growth ($FuelP\_L1_{jt}$), and calendar year ($Year_{jt}$), each of which is measured as explained below:

- $MTOW_j$ is the same variable used in the cross-sectional models;
- $4Engines_j$ is a dummy taking *1* if model *j* is a four-engine aircraft and *0* if it is a two-engine aircraft*;*
- $CumQ\_L1_{jt}$ is the cumulative quantity for the aircraft family associated with aircraft model *j* at the end of the prior year;
- $WGDP\_L2_{jt}$ was world real GDP growth expressed as percentage deltas from the trend and lagged two years, where the trend is established using the Hodrick-Prescott filter;[43]
- $FuelP\_L1_{jt}$ was the real price of jet fuel lagged one year, and
- $Year_{jt}$ is the calendar year associated with each model *j* and time *t.*

When estimating the model, we included a dummy variable for WB aircraft, along with an interaction term with the $MTOW_i$ variable. This resulted in a unique slope coefficient on $MTOW_i$ as well as a different intercept for WB. This meant a separate model estimated for each of WB and narrow-body (NB) aircraft, as shown in the specification presented in Figure 6. Variations on both the MTOW and Seat Miles pooled OLS models included production rate for each aircraft family as an additional independent variable. Our estimated models are (standard errors are included under the parameter estimates):

- For WB aircraft:

$$\begin{aligned} ln(p_{jt}) = 13.01 + \underset{(.140)}{1.147}\, ln(MTOW_j) - \underset{(.039)}{0.253}\, (4Engines_j) - \underset{(.008)}{0.031}\, ln(CumQ\_L1_{jt}) \\ + \underset{(.738)}{1.371}\, (WGDP\_L2_{jt}) - \underset{(.013)}{0.038}\, (FuelP\_L1_{jt}) - \underset{(.002)}{0.011}\, Year_{jt}, \end{aligned}$$

- For NB aircraft, the interaction terms result in a unique intercept and MTOW coefficient, with the remaining coefficients remaining the same as for WB aircraft:

$$ln(p_{jt}) = 4.37 + \underset{(.738)}{1.907}\, ln(MTOW_j)$$

Figure 6 compares MBA-reported data points to the projected prices using the estimated models.

[43] Robert J. Hodrick and Edward C. Prescott, “Postwar U.S. Business Cycles: An Empirical Investigation,” *Journal of Money, Credit and Banking* 29, No. 1 (February 1997): 1–16, http://www.jstor.org/stable/2953682.

$$p_{WB\,jt} = 447{,}111\; MTOW_j^{1.147}\; .777^{4Engine_j}\; CumQ\_L1_{jt}^{-.031}\; 1.371^{WGDPc\_L2_{jt}}\; 0.963^{FuelP\_L1_{jt}}\; 0.989^{Year_{jt}}$$

$$\left(p_{NB\,jt} = 79.4\; MTOW_j^{1.907}\right)$$

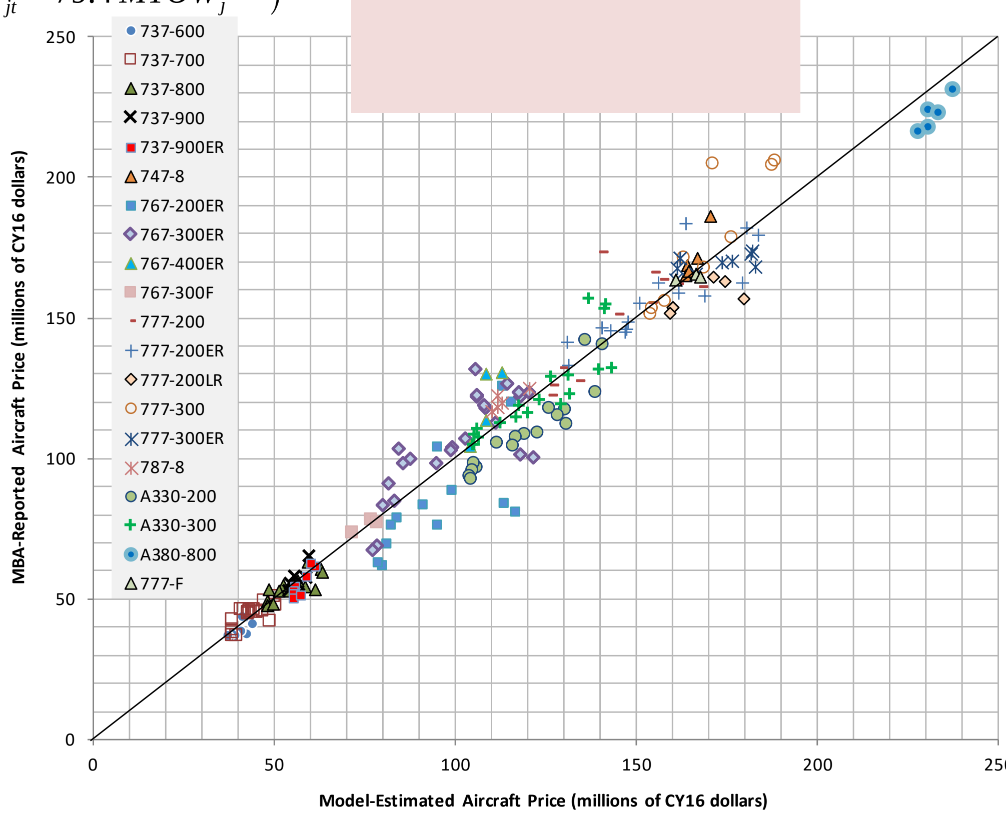

Figure 6. MTOW Panel Data Model

All of the parameter estimates for the preferred model shown in Figure 6 are significantly different from zero at p = .06 or better. Estimates for the coefficient on $CumQ\_L1_{jt}$ indicate equivalent price improvement curve slopes of 97.9 percent. This is much shallower than typical cost improvement curves and is consistent with the economics literature. The estimates on $WGDP\_L2_{jt}$ suggest that if world real GDP growth is one percentage point above trend two years prior to aircraft delivery (say, 4.4 percent versus the 3.4 percent growth trend estimated for 2017 using the Hodrick-Prescott filter), the price will be 1.4 percent higher than if GDP growth was at trend.

Estimates for the fuel price coefficients indicated that a 1 dollar per gallon increase in fuel price one year prior to aircraft delivery results in a 3.8 percent decrease in price. The reasonableness of this estimate was tested by an approach similar to that taken by Markish,[44] where changes in fuel costs were related to changes in discounted life cycle costs associated with the aircraft. Predicted changes in aircraft price associated with

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[44] Jacob Markish, “Valuation Techniques for Commercial Aircraft Program Design” (MS thesis, Massachusetts Institute of Technology. 2002), http://hdl.handle.net/1721.1/16871.

changes in fuel cost were around 10 percent of the change in the discounted life cycle cost associated with the same fuel cost change. This seems reasonable, given that substantial portions of fuel price changes will be passed along to airline customers or result in changes in demand for seats as opposed to being absorbed by the aircraft manufacturers as price decreases. Also, only a portion of annual price changes will be interpreted by the market as affecting future prices.

The time trend parameters on $Year_{jt}$ indicated a decrease in real prices of 1.1 percent per year. Note that the GDP deflator was used to escalate nominal prices to constant 2014 dollars. For the recent period, this is consistent with a 1 percent annual rise in nominal prices.

E. Price Discounts from List Price and Boeing Financial Data

Estimates of transaction prices for commercial aircraft are often expressed as discounts from list prices. We calculated discounts from Boeing's 2016 list prices (which were unchanged from the published 2015 values) using both the MBA data and estimated prices from the models, including error bounds. An example using the pooled OLS MTOW model is shown in Figure 7.

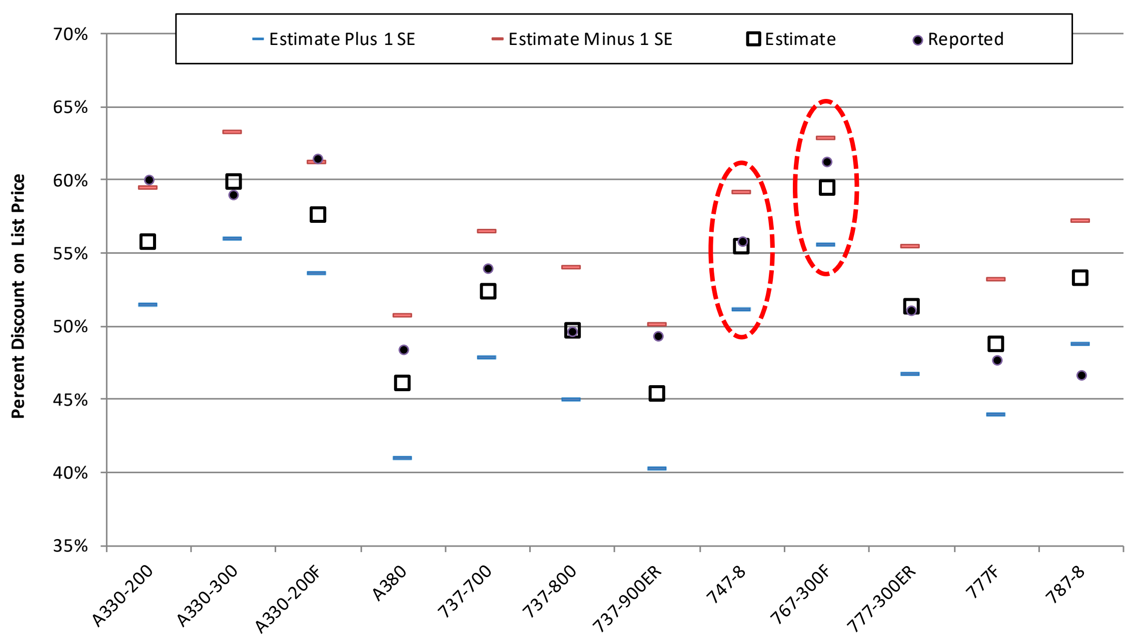

Figure 7. Discounts from 2016 List Prices: MTOW Model

For the WB aircraft, the average discount for Boeing aircraft was 53 percent for the MBA data and 52 percent for the MTOW model estimates. Over the entire Boeing portfolios, the average discount was 53 percent for the MBA data and 52 percent for the MTOW

model estimates. For the Boeing portfolio we also calculated weighted average discounts, discussed in more detail below.

As a means of validating the models and the underlying MBA data, we calculated the weighted average discount for Boeing based on their reported financial data and aircraft deliveries for 2016. Boeing reported revenue by Segment including Commercial Airplanes (BCA), where revenue was booked at aircraft delivery. A small portion of BCA revenue is from commercial after-sales support (CAS) and was estimated to be $6.5 billion in 2014.[45] Extrapolating this value forward using the annual growth rate from 2011 to 2014 of 6.4 percent, we arrived at a value of $7.355 billion for 2016.

We calculated aircraft sales revenues by subtracting CAS revenues from total BCA revenues for 2016:

$$R_t = \$65{,}069\text{M} - \$7{,}355\text{M} = \$57{,}714\text{M}.$$

Annual delivery quantities by model (q_{jt}) and list prices by model ($\overline{p}_{jt}^{\,*}$) are available for each model from Boeing's website. Given these values, the weighted average 2016 discount (D_t) was:

$$D_t = \frac{R_t}{\sum_j \overline{p}_{jt}^{\,*} \mathrm{q}_{\mathrm{jt}}} - 1 = \frac{\$57{,}714M}{\$121{,}453M} - 1 = 52.5\%. \tag{11}$$

Replacing R_t with the model estimates for each model $\hat{p}_{\mathrm{jt}}$ yielded the estimated weighted average discount ($\hat{D}_t$):

$$\hat{D}_t = \frac{\sum_j \hat{p}_{\mathrm{jt}} \mathrm{q}_{\mathrm{jt}}}{\sum_j \overline{p}_{jt}^{\,*} \mathrm{q}_{\mathrm{jt}}} - 1. \tag{12}$$

$\hat{D}_t$ varied between 50.2 percent and 51.3 percent, depending upon which models were used to estimate $\hat{p}_{\mathrm{jt}}$. When the MBA values were used for $\hat{p}_{\mathrm{jt}}$, $\hat{D}_t$ = 50.1 percent. These results give some assurance, that at least at the top level, the MBA data and the models are consistent with Boeing's revenue derived from aircraft sales.

Another important result from the models was the estimated downward trend in real transaction prices over the sample period. Boeing applies a weighted average of input price inflation rates when escalating list prices from year to year. Given this, and the

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[45] Sean Broderick, "Boeing Revives Emphasis On Post-Delivery Business," Inside MRO, MRO-Network.com, June 10, 2014, http://aviationweek.com/mro/boeing-revives-emphasis-post-delivery-business.

model results, we should expect calculated discounts from list prices to be increasing over time as list prices rise at a higher rate than transaction prices. This is what we see where D_t increased from 34–39 percent (depending on assumptions regarding CAS revenue) in 2004 to 52.5 percent for 2016 as calculated above. These additional calculations using publicly available Boeing data also confirm modeling results and the underlying data used.

4. KC-46A and PAR Program Applications

In this chapter, we apply information from the economics literature, our modeling results, and other relevant data to help estimate “fair and reasonable” prices for the commercial aircraft platforms used for the KC-46A and PAR programs. As described in the introduction, the pricing challenges for each of these cases is different.

A. KC-46A

The KC-46A’s commercial platform, the 767-2C, has features that have no direct analog in the commercial aircraft database. Boeing considers the platform to be based on the 767-200ER passenger aircraft, even though it has freighter floors and doors associated with the longer 767-300F. While the 767-300F is still in production, the last 767-200ER was delivered in 2008.

The price estimating models do provide some flexibility in producing estimates of transaction prices. The model can take into account the implied value to the market of some characteristics of the 767-2C, such as the increased MTOW (415,000 lbs. vs 396,000 lbs. for the 767-200ER and 413,000 lbs. for the 767-300F). Applying corresponding inputs to the MTOW cross-section model yields a point estimate in calendar year (CY) 2016 dollars of $81.5 million. As would be expected, the model yields a similar price for the 767-300F at $80.0 million; this compares with $77.1 million for the reported MBA price. The price estimates do not include the additional 767-2C content associated with provisions specific to the KC-46A not captured in the higher MTOW. There is little or no contemporaneously available market pricing data for these “like kind” modifications, other than their total value as revealed in the competition.

The competitive nature of the initial down-select, including NTE prices for production lots through the end of the planned program, meant that the fair value of all 767-2C features was revealed and should guide future prices. In other situations, one approach to addressing the value of like-type features would be to add their cost basis along with a representative mark-up to price. The costs could be based on analogies, cost estimating relationships, or cost data from the seller. The government has the right to ask for seller cost data, although it need not be TINA-compliant.

However, the overall market conditions and the specifics of the 767 production that were obtained at the time of the 2011 competition (including expectations regarding the future) are likely to be different now. The MBA data, price estimating models and Boeing financials show a continuing downward trend in real prices. Also, given additional

767-300F orders and deliveries for Federal Express, the overall 767 program is delivering aircraft at a rate higher than planned in 2011; given the relationship between cost and price for a mature program (where the z_t argument goes to 0 in the $p_t = \dfrac{c_t + z_t}{1-((1\text{-}s)/E)}$ equilibrium relation, and the denominator is less than 1) the delivery rates indicate a lower price, as fixed costs are allocated over more units in a given year.

We are able to capture the overall price trend by applying the pooled OLS model using 767-2C characteristics and time series inputs, including projections to 2020. Projections for GDP growth and fuel prices are taken from International Monetary Fund (IMF) forecasts,[46] while additional deliveries reflect Boeing planned 767 delivery rates of two aircraft/month (up from prior values of one aircraft/month). This is shown in Figure 8, along with data and model results from the 767-200ER, model estimates of the 767-2C, as well as data for the 767-300F.

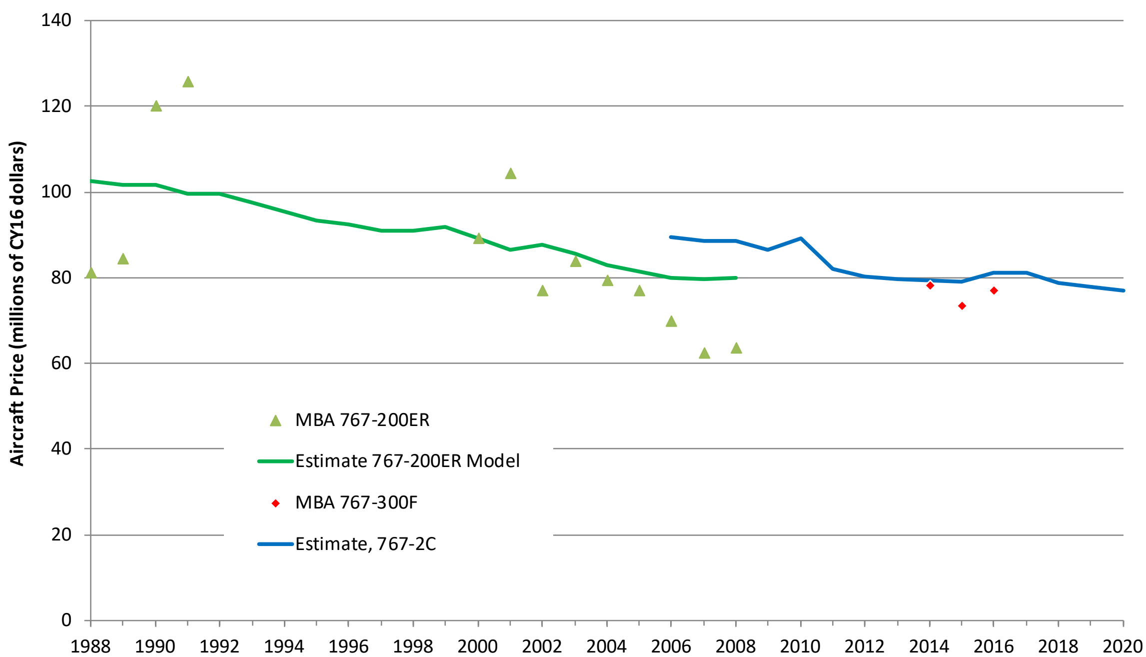

Figure 8. Panel Data Model Estimates for the 767-2C with Comparisons

The estimate for the 767-2C is $81.3 million in CY16 dollars (note that this excludes KC-46A-specific provisions that are not captured in the model). Comparing this value to the model-predicted 2011 value shows an estimated decrease in price of 1.3 percent. In the case of 2017, the longer-term decrease in real prices is offset by price increases indicated by the model due to decreases in the fuel prices. This effect dissipates

46 IMF, "World Economic Outlook, Subdued Demand: Symptoms and Remedies."

for future years with estimated prices decreasing to 6.0 percent below the 2011 value by 2020.[47] This indicates that there is room for negotiation below the NTE values determined in the 2011 competition. For later lots where the NTEs are subject to adjustment based on an EPA clause, if the price trends indicated by the data and model (including evidence from Boeing's financial data) diverge from the price index specified in the EPA clause, there is additional potential to negotiate prices below the NTEs (as adjusted by the EPA).

As mentioned in the description of the regression analyses, we cannot separate out the supply-side effects on price of increases in production rates from the demand side effects (GDP growth in our preferred models) using the MBA data. However, given general knowledge of aircraft industry cost structures as well as specific information from Boeing's financial reporting, we can analytically derive an estimate of cost effects of the higher production rates. The cost/price effects of increased 767 production rates can then be approximated by employing a "rate slope" term as estimated in DoD programs where price is based on cost.[48] Information from Boeing financial statements regarding the cost of reducing 747 production rates provides a way to calibrate the rate slope model for commercial aircraft production.

The Boeing 10-K report for 2015 notes a carry-forward loss of $850 million for the 747 program recognized in the fourth quarter of 2015. The loss is associated with both pricing pressures and cost increases associated with the decrease in production rate in 2016 from 1.3/month to 1/month, and then to .5/month later in 2016, with production rate increasing to 1/month in 2019. As there was no change in total program accounting quantities, the increased costs are associated with the additional two years of production (end date of 2021 vs. 2019) required to deliver the program quantity compared to the earlier delivery profile. To approximate the contribution of pricing pressure on the total $850 million loss, we refer to the difference between MBA's "base value" and "market price" estimates; for 2016, the market price is 3 percent below the base value.[49] When this difference is applied for the remaining programmed aircraft (and accounting for inflation in prices), the estimated difference is $330 million. This leaves $520 million associated with the two years of additional fixed costs due to the production stretch-out. Assuming nominal dollars accounted for in 2020 and 2021, annual fixed costs are calculated at $239 million in constant CY16 dollars.

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47 This estimate is based on IMF forecasts of the price of Brent crude, which is projected to increase from an average of $43/barrel in 2016 to $54/barrel in 2019 (all nominal dollars).

48 This approach was suggested by Dr. David Marzo of CAPE/CA.

49 As the 747-8F will dominate future 747 production, we use it as price/cost basis for the following analyses.

Taking the 2015 747 deliveries at 18/year as a baseline rate, we can derive estimates of the unit cost effects of production rate. For 2015, we assume a 15 percent margin on cost, consistent with overall Boeing performance for that year. Given the estimate of \$239 million (CY16\$) annual fixed cost, unit variable costs are \$146 million (CY16\$). With this information, estimates of unit costs and fixed cost percentages at different delivery rates can be calculated. This is shown in Figure 9, where delivery rates from 6/year to 18/year are included, consistent with 2015 experience and forecasts through 2021.

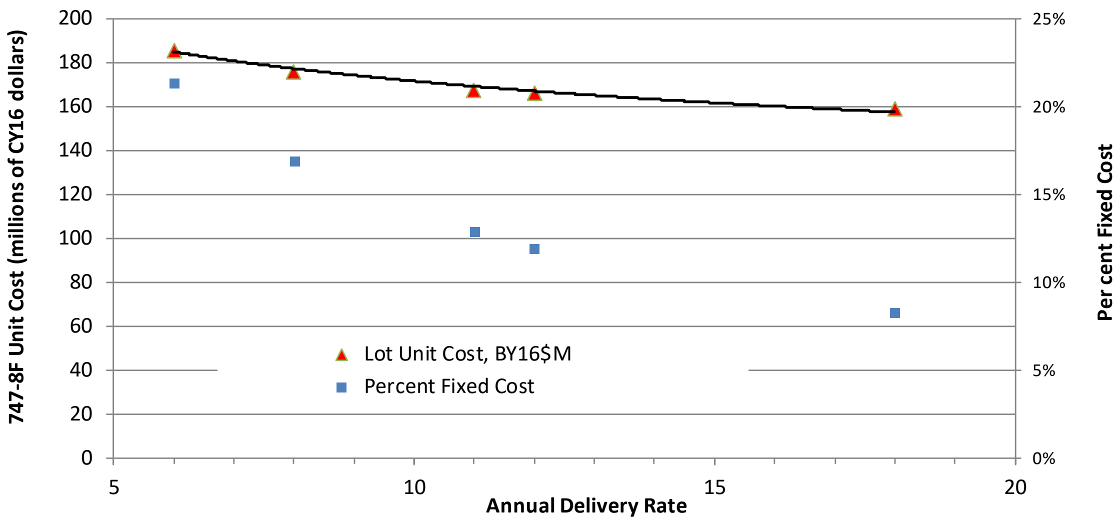

Figure 9. Unit Cost and Fixed-Cost Percentage Estimates for 747 Production

The curve fitted to the unit costs generalizes the relationship between annual quantities and unit costs; it is known as the "rate curve" relation,

$$c_t = \alpha \boldsymbol{q}_t^{\beta}, \tag{13}$$

where $\boldsymbol{q}_t$ is the annual delivery rate. For the 747 example above, the estimated β coefficient is -.146, corresponding to a 90.4 percent rate slope; this is within the range of parameters estimated for military aircraft programs.

Taking model-estimated prices for the 767-2C and insights from the above 747 analyses, we can estimate cost decreases driven by increases in production rates between the plan at Boeing's 2011 bid and the current plan. These differences indicate a 38 percent steady state increase in production rate. Baselining cost values to 767-2C price estimates for 2015 and applying the 15 percent margin assumption allows us to generate estimates of cost savings associated with the higher production rates. Using the 90.4 percent rate slope, we estimate annual unit cost savings of around \$3 million (CY14) for the steady state years (2017 to 2026), corresponding to a 2 percent decrease in cost.

The 767-2C presents a special case, as price discovery at the time of competition between alternative Tankers means that there is less uncertainty for future purchases. However, we see in the application of our models and other information that there are both program-specific factors (higher than previously planned production rates) and overall industry trends (increases in nominal prices over time that are less than overall inflation) that would indicate prices below the NTEs could be negotiated for future lots.

B. Presidential Aircraft Replacement (PAR) Program

In some ways the purchase of 747-8I aircraft for use in the PAR is more straightforward than the 767-2C procurement. There are no mission-specific provisions that require an amended type certificate; the Boeing Business Jet (BBJ) VIP version of the 747-8I, which most closely resembles the base aircraft for the PAR, also does not have its own amended type certificate. Given this, we can lean more heavily on the reported prices paid by commercial airlines and the models based on those data.

There are two complications in the PAR 747-8I price analysis. The first is the status of the Air Force as a relatively small customer for the 747-8I, indicating a price higher than the market average. Another complexity is the specification of the base PAR aircraft as a BBJ version without standard airline interiors. There are data and models that can help inform adjustments needed to address these conditions.

We begin the discussion with the presentation of data and price estimating results for the 747-8I. Figure 10 shows the panel regression model estimates along with the MBA data through 2016.

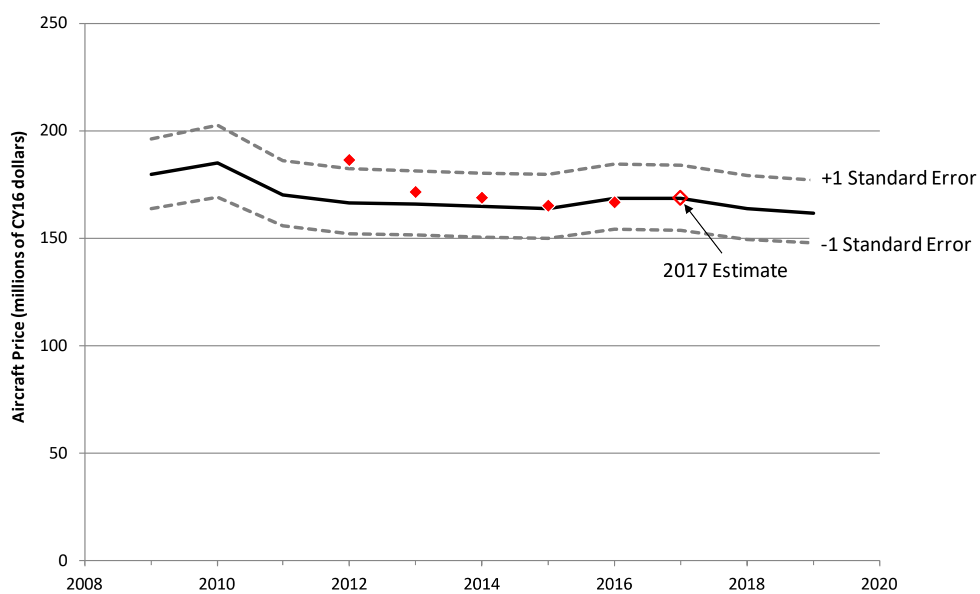

Figure 10. MBA Data and Model Estimates for 747-8I Prices

Given the same economic inputs as the 767-2C price estimate, the 747-8I price estimate for 2017 is \$168.3 million (CY16), which inflates to \$171.3 million in 2017 dollars (assuming the Office of Management and Budget-projected GDP deflator for 2017). Given the assumptions behind the MBA data, this is the market price for a typical airline transaction, with interiors included.

To adjust for potential lower quantity discounts associated with the Air Force buy of two or three aircraft, we employ the regression coefficients estimated by Onishi and apply them using data for 747-8 orders (including both 8I and 8F models, consistent with the data used in model estimates). We set the intercept value such that the average of the calculated quantity discounts is standardized to zero. The resulting relationship for 747-8I quantity discounts is, for buyer i,

$$D_{it} = -.038 + .10\frac{Order\ Quantiy_{it}}{Total\ Accumulated\ Quantiy} + .60\frac{Airline\ Accumulated\ Quantiy_{it}}{Total\ Accumulated\ Quantiy}, \quad (14)$$

where $\sum_{t=1}^{k} D_{it} = 0$. The total order quantity for the 747-8 through October 2016 is 143 aircraft. For the PAR, where either a two- or three-aircraft buy would be accomplished in a single order,

$$q_{it}^{N} = q_{it}^{A} = \frac{Order\ Quantiy_{it}}{Total\ Accumulated\ Quantiy} = \frac{Airline\ Accumulated\ Quantiy_{it}}{Total\ Accumulated\ Quantiy} = .014 \text{ or } .021,$$

with calculated quantity discounts of -2.8 percent or -2.3 percent, respectively. This means that DoD must pay a quantity premium of 2.8 percent or 2.3 percent above the mean price. This is shown graphically in Figure 11 along with calculation results for the historical orders.

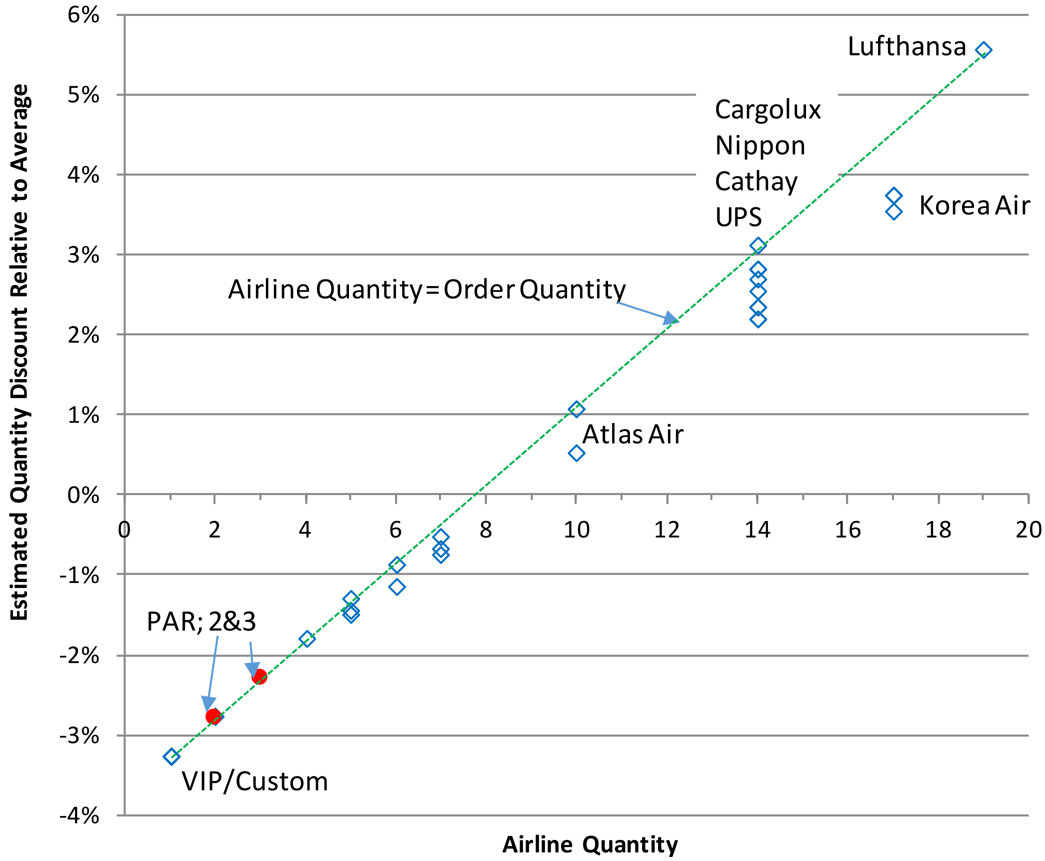

Figure 11. Calculations of Quantity Discounts for 747-8 Orders

Assuming the estimated price of $171 million aligns with the average quantity discount ($\Delta D_{it} = 0$), the adjusted values for the PAR quantities are $175 million for three aircraft and $176 for two aircraft. Most of the single orders for one aircraft were for VIP aircraft—these are calculated at a still higher price (ignoring adjustments for Boeing-installed interiors).

The MBA prices and Boeing list prices include typical airline interiors, including BFE. In order to estimate the price to the Air Force for a "green" aircraft (an aircraft without a full interior), we need some estimate of the value of the excluded interior components. We have several sources for data that can help us address this question. An estimate was provided to IDA directly from MBA in 2015 of a typical airline interior for a 747-8I. The total value of $40 million included certification and other non-recurring costs of up to 40 percent of total costs. This leaves a marginal cost of $26 million when converted to 2017 dollars. Other data to help put this value into perspective were available for 737 and 777 interiors. For the 737, interior values were based on two data sources; Nelson et al. (2003) estimated interior values for the 737 based on differences between list prices for the 737 BBJ (a business jet version of the 737 without interiors)

and 737-700 passenger aircraft.[50] In a separate analysis, IDA calculated the difference between the 737 green BBJ aircraft used for the Air Force C-40 executive jet and comparable prices estimated by IDA's time series model for an airliner (including interiors) with the same MTOW as the C-40. For the 777, a financial news report[51] indicated the cost of installing a new interior into a used 777-200ER interior of $20 million. The relationship between the value data and aircraft interior square footage is shown in Figure 12; this provides some confidence in the MBA estimate.

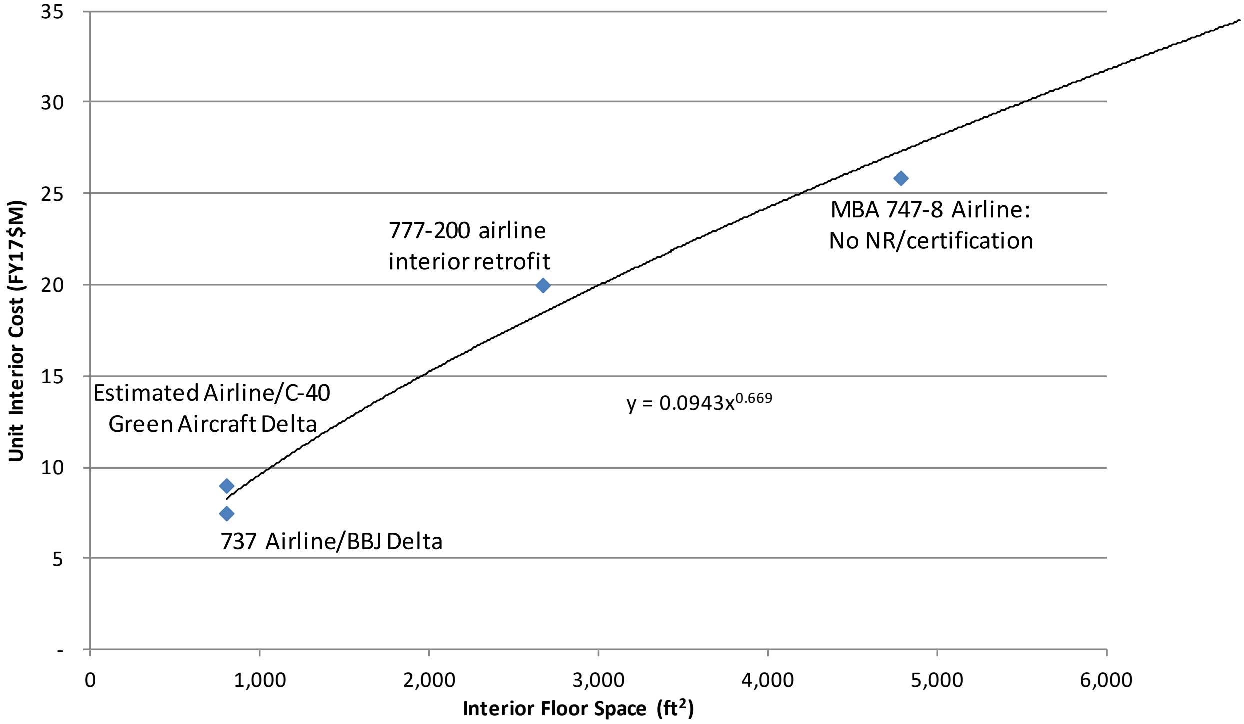

Figure 12. Airline Interior Value vs. Square Footage

Subtracting the MBA-estimated interior costs from the price estimates for the 747-8I results in a green aircraft estimate of $150 million for a two-aircraft buy.

C. Summary

The different challenges associated with estimating prices for the KC-46A and the PAR mean different approaches to applying available data, economic theory, and pricing models. The long time horizon for the KC-46A program means that it is important to take

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50 Nelson et al., "Purchase Price Estimate for the KC-767A Tanker Aircraft."

51 Dhierin Bechai, "Does a $7 Million Boeing 777-200ER Compare to a Brand New Dreamliner? (Part 1)," Seeking Alpha, March 8. 2016, https://seekingalpha.com/article/3956517-7-million-boeing-777minus-200er-compare-brand-new-dreamliner-part-1.

into account both the effect of general industry pricing trends and changes in the specifics of 767 production economics. Our analyses of both of these effects indicate that the government may be able to pay lower prices than the NTE prices set in the original competition. For the PAR case, current market data for the 747-8I are more relevant. However, even those data must be adjusted for the unique circumstances of the PAR program. These include the relatively low order quantity and the exclusion of airline interiors. These factors are addressed using an economic model quantifying price discrimination/quantity discounts in the aircraft industry, and micro data on the cost of aircraft interiors.

5. Commercial Aircraft Pricing Lessons Learned

A. Commercial Aircraft Pricing Tools

Price determination by negotiation for commercial items will generally only occur if the supporting markets are not purely competitive. In the case of commercial aircraft, the market is a duopoly where prices are above those that would be paid if the market were purely competitive. The specifics of this market have been explored in some detail in the economics literature. The resulting game-theory models are insightful but without much empirical gain. We were able to make use of the consultant-reported transaction prices to quantify price drivers, both on the demand and supply side of the market, through least-squares regression analyses. These models explain most of the variance in prices across aircraft models and time; utility associated with commercial airline services, moving people and goods speedily across long distances, can be proxied effectively by a small number of variables, while supply/cost effects can be mostly captured in a few dimensions. An important insight from the models and supporting data is the long-run decrease in real commercial aircraft prices. This could have an important impact on the pricing of future KC-46A procurements.

The models are useful in establishing baseline values for commercial aircraft used by the military. In our application of the models to the KC-46A and PAR programs, we needed additional tools and data to address specifics of those programs/aircraft. These included cost drivers not captured in the models (production rate effects), the valuation of non-standard equipment (the lack of airline interiors for VIP aircraft) and a model of price discrimination/quantity discounts.

B. Implications for Other Commercial Items

Several steps in the analysis of the commercial aircraft pricing for military applications would be relevant in negotiating prices for other commercial items:

- Understand the market in which the seller operates. This would go beyond "market research" and should address market dynamics as described by economic theory.
- Model market prices as they relate to both supply (cost) and demand (utility) side drivers. This will be challenging in that most commercial items bought by

DoD and subject to price negotiation will not be as homogenous as commercial aircraft.

- Make use of the seller’s publicly available financial data to put available pricing data into perspective, and to better understand the seller’s business model.
- Given the existence of “like type” modifications to items available on the commercial market, it may be advantageous to estimate the discrete costs of these modifications.

Illustrations

Figures

Tables

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Abbreviations

ATC	Amended Type Certificate
BBJ	Boeing Business Jet
BCA	Boeing Commercial Airplanes
BEA	Bureau of Economic Analysis
BFE	Buyer-Furnished Equipment
BLS	Bureau of Labor Statistics
CAS	Commercial After-sales Support
CY	Calendar Year
DFARS	Defense Federal Acquisition Regulation Supplement
DoD	Department of Defense
DOT	Department of Transportation
EPA	Economic Price Adjustment
FAR	Federal Acquisition Regulation
FASA	Federal Acquisition Streamlining Act
FY	Fiscal Year
GDP	Gross Domestic Product
IDA	Institute for Defense Analyses
IMF	International Monetary Fund
lb	Pound
M	Million
MBA	Morton, Beyer, and Agnew
MTOW	Maximum Take-off Weight
NB	Narrow-body
NDAA	National Defense Acquisition Act
NM	Nautical Mile(s)
NTE	Not-To-Exceed
OLS	Ordinary Least Squares
OSD-CAPE	Office of the Secretary of Defense, Cost Analysis and Program Evaluation
PAR	Presidential Aircraft Replacement
SAR	Selected Acquisition Report

TINA	Truth in Negotiations Act
TY	Then-Year Dollars
U.S.C.	United States Code
US	United States
VIP	Very Important Person
WB	Wide-body

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14. ABSTRACT

The procurement of commercial items presents both opportunities and challenges for the Department of Defense. Among the challenges is the negotiation of "fair and reasonable" prices with suppliers where competitive sources are not relevant. This paper presents analyses to address this challenge for commercial aircraft that serve as the basis for military systems. Using insights from the economics literature on aspects of the commercial aircraft market, we develop estimating models for aircraft price that take into account both supply and demand drivers, across both aircraft models and time. These models are applied to the KC-46A airborne tanker and Presidential Aircraft Replacement (PAR) programs, prices of which are subject to negotiation. Other factors affecting the commercial aircraft market and aircraft used in these programs (the Boeing 767 and 747), are also addressed. Lessons learned applicable to the general problem of negotiation of contracts for commercial items are enumerated.

15. SUBJECT TERMS

Commercial aircraft market; Boeing; KC-46A; Presidential Aircraft Replacement; price estimating; price estimating models; commercial items; economic models

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